Simulated Water Well Performance on Mars

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This paper describes improvements in our understanding of the nature and location of massive ice sheets on the surface of Mars as well as refinements made to a technical approach for extracting significant quantities of water from these ice sheets using a technique known as a Rodriguez Well. Recently published discoveries on Mars have reinforced the evidence for the existence and structure of these massive buried ice sheets. Using this improved understanding of the feedstock material, this paper describes estimates made regarding basic characteristics – mass, power, configuration, etc. – of a system that can access and extract water from these ice sheets. This paper then summarizes the basic operation of a Rodriguez Well and describes a computer simulation used to estimate the performance characteristics of this type of well. This simulation was built and used to predict the performance of similar wells operated in the Earth's Arctic and Antarctic regions. However, physical parameters (e.g., specific heat and gas constant for air, heat transfer between water and air and between ice and air, etc.) used in the simulation represent a terrestrial environment and must be adjusted for a Martian environment. A pair of experiments designed to determine the appropriate values for these parameters under Martian conditions are described. Until results from these experiments are available, published results from other sources are used in the simulation to gain an understanding of the effect that could be seen. These provisional results are discussed.

I. Introduction

The surface of Mars once had abundant water flowing on its surface [1], but there has been a general perception that this surface is now completely dry. Recently, several lines of research have shown that there are sources of potentially large quantities of water at many locations on the surface, including regions considered candidates for future human missions. If these reservoirs of water can be accessed in support of human Mars missions, a dramatic change in the approach to these missions could result.

Many past studies of human Mars missions assumed a complete lack of water derivable from local sources, driving up the level of sophistication needed for systems like life support, and denying the opportunity to reduce the mass needed for consumables like propellants. However, studies carried out as part of NASA's Evolvable Mars Campaign effort [2] examined the impacts of a "water rich" human Mars mission scenario [3]. For this assessment, the elements of a human Mars mission that would most benefit from the largely unconstrained availability of water were identified and the "typical" quantities of water that would be used by crews under this scenario were estimated. Sources of feedstock material from which water could be extracted were then identified based on the most recently available data for the surface of Mars. These feedstock materials tended to fall into two broad categories: regolith/minerals and ices. There have been a number of studies of the use of local resources – commonly known as in-situ resource utilization (ISRU) – carried out to investigate where and how these resources improve the overall performance of future human missions. Results from one assessment of ice as a feedstock is discussed in a recent paper [3], illustrating how new concepts continue to be evaluated in an ongoing effort to improve mission performance. A separate paper [4] discusses representative results from numerous assessments of concepts using regolith/minerals as a feedstock. A third paper compares the operational implications, in terms of system hardware mass and power required, of using each of these feedstock materials to support future human Mars missions [5]. These papers, and others of a similar nature, have

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shown concepts and technologies that can in fact result in significant savings of launch mass and improved performance for these future missions. However, no single option among these concepts is clearly better than the others in all cases – each represents a tool in the ISRU toolbox, providing options to improve missions sent to diverse locations with differing feedstock options. Each of these ISRU tools still requires refinement to understand where and how they can be best employed.

This paper will focus on improvements in our understanding of the feedstock and refinements being made to the technical approach described in the paper by Hoffman, et al [3] – that is, extracting significant quantities of water from massive ice sheets using a technique known as a Rodriguez Well. Recently published discoveries on Mars have reinforced the evidence for the existence and structure of massive buried ice sheets. These discoveries will be summarized in Section II of this paper. Using this improved understanding of the feedstock material, estimates have been made regarding the characteristics – mass, power, configuration, etc. – of a system that can access and extract water from these ice sheets. These characteristics are described in Section III. Sections III and IV summarize the basic operation of a Rodriguez Well and describe a computer simulation used to estimate the performance characteristics of this type of well. This simulation was built and used to predict the performance of similar wells used in the Earth's Arctic and Antarctic regions. However, this simulation uses physical parameters (e.g., specific heat and gas constant for air, heat transfer between water and air and between ice and air, etc.) representative of a terrestrial environment that must be adjusted for a Martian environment. Section IV also describes these physical parameters and sources from which appropriate parameters for a Martian environment could be drawn. Some of these parameters will need to be revised based on experiment. A series of experiments designed to determine the appropriate value for these parameters under Martian conditions is described in Section IV. Until results from these experiments are available, published results from other sources are used in the simulation to gain some understanding of the effect that could be seen. These provisional results are discussed in Section V. Finally, Section VI summarizes the progress described in this paper and discusses some general observations regarding the general direction and application of this capability.

II. Water Sources on Mars

Contemporary sources of water on Mars are known to exist in a variety of locations and in several different forms. Hoffman et al [3] discussed the potential Mars water "inventory," divided into roughly six categories [6], in the context of a human Mars mission. This paper also examined potential uses of local resources, particularly water. This assessment indicated that as much as 68 metric tons of water (approximately 18,000 gallons) could be used by each crew of four during a 500 sol mission on Mars [3]. Of the six identified water source categories, several were ruled out as unlikely sources for use in support of human missions:

- Surface water ice can be found in the Polar Regions, but the poles were ruled out as they are unlikely locations for human missions (at least early missions).
- Atmospheric water vapor was deemed to be in too low of a concentration to be a useful source if large quantities were required.
- "Recurring Slope Lineae" (RSL) [7] have been interpreted as intermittent flows of briny liquid water and this was confirmed by the Mars Reconnaissance Orbiter (MRO) Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) spectrometer in 2015. However, the water source was unclear, and some interpreted this as more evidence of aquifers exposed by these slopes. A global search for subsurface liquid aquifers by the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) and Shallow Radar (SHARAD) failed to detect any indication of liquid water within 200-300 m of the surface anywhere on Mars [8]. These sources were considered too uncertain in terms of both location and quantity to be used as the basis for planning a future human mission.
- Remote sensing data confirmed previous predictions of extensive ground ice within one meter of the Martian surface poleward of 50° north and south latitude with a concentration of 20-90% [9] with an estimated thickness of 5-15 kilometers [8]. But, as with the polar locations, these deposits were considered to be outside the range likely to be selected for human surface missions.

Of the remaining two sources – water sequestered in minerals and massive ice sheets – both are considered viable for use by future human missions and work continues to develop technologies to extract water from them.

Discoveries published since Hoffman et al [3] have reinforced our knowledge about the existence, location and form of buried ice sheets. Terrain features called Lobate Debris Aprons (LDAs), Lineated Valley Fills (LVFs) and

Concentric Crater Fills (CCFs) [10] all bear similarity to terrestrial glaciation features (Fig.) and are widely distributed in the Martian mid-latitudes (Fig.). The SHARAD and MARSIS radars also provided data that was similar to that seen from radars used to investigate ice formations on Earth [11]. In January 2018, Dundas et al [12] published the results of their work, finding visual evidence of the ice sheets assumed to be buried within these terrain features. Several examples are shown in Figure 3. Spectral data, gathered by the MRO CRISM instrument, have shown that these exposed features are almost pure water ice.

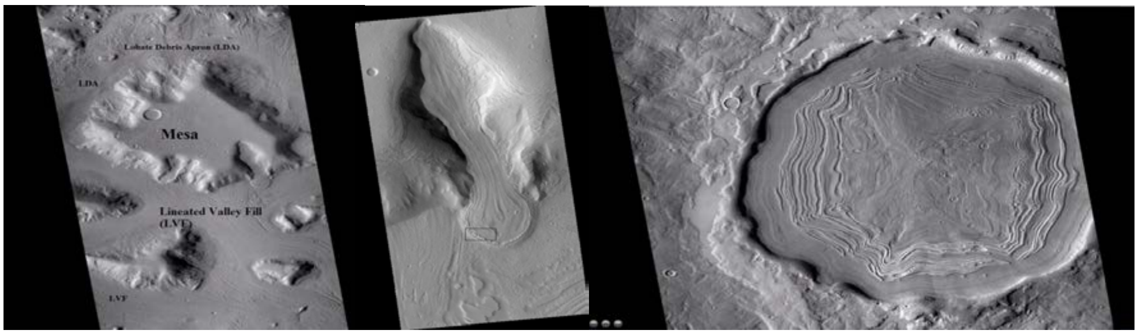

Fig. 1 LDA, LVF and CCF Martian Glaciation Features (MRO Context Camera) [NASA Images]

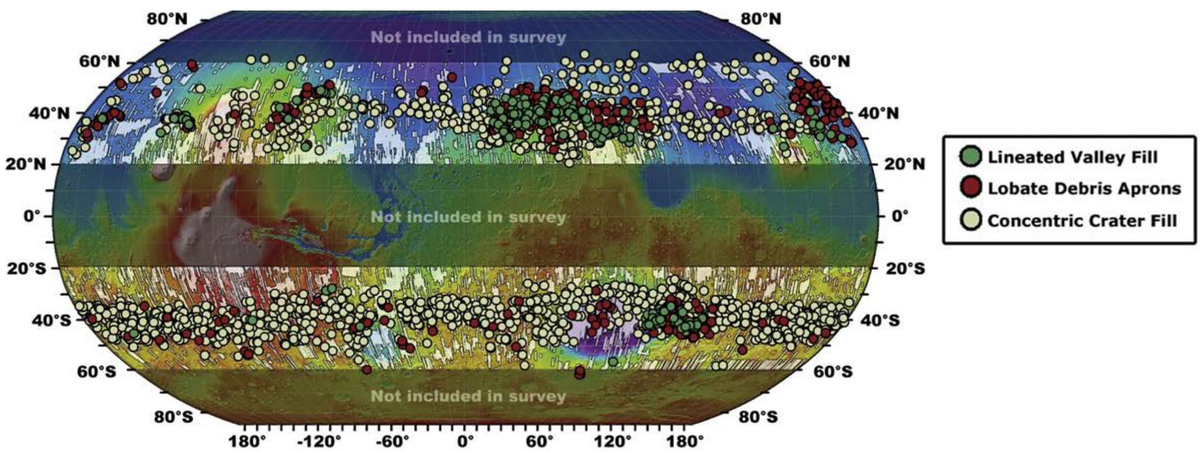

Fig. 2 Global Distribution of LDA, LVF and CCF features [10]

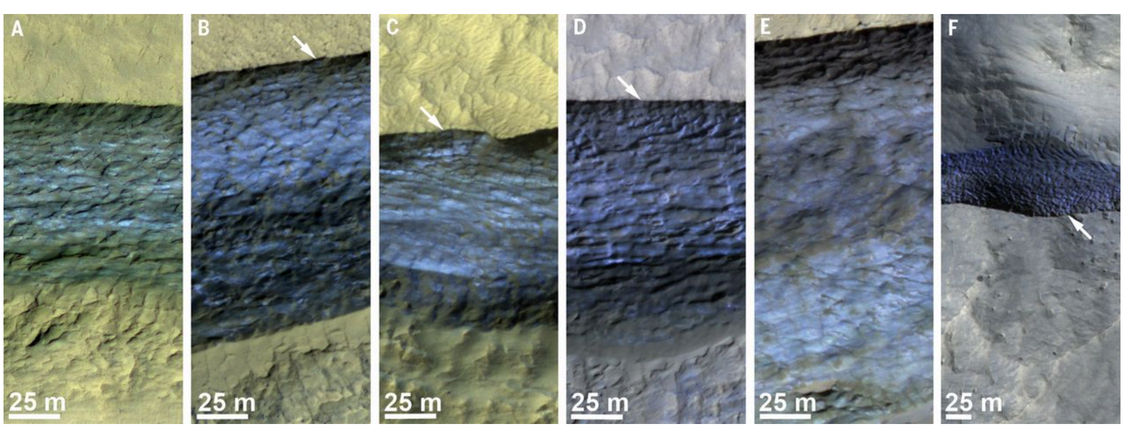

Fig. 3 Examples of recently discovery exposed ice scarps on Mars [12]

To provide a sense of scale, Figure 4 shows one of the Dundas ice scarps with an SLS (cargo) launch vehicle at the same scale. In addition, the previously mentioned 68 metric tons of water that could be used by a single crew of four during a 500 sol Mars surface mission is also shown to scale. These exposed sections of buried ice sheets are a relatively small portion of the entire body of ice with which they are associated. This visual comparison indicates that the quantities of ice available for making water vastly out-scale the need for at least these early surface missions.

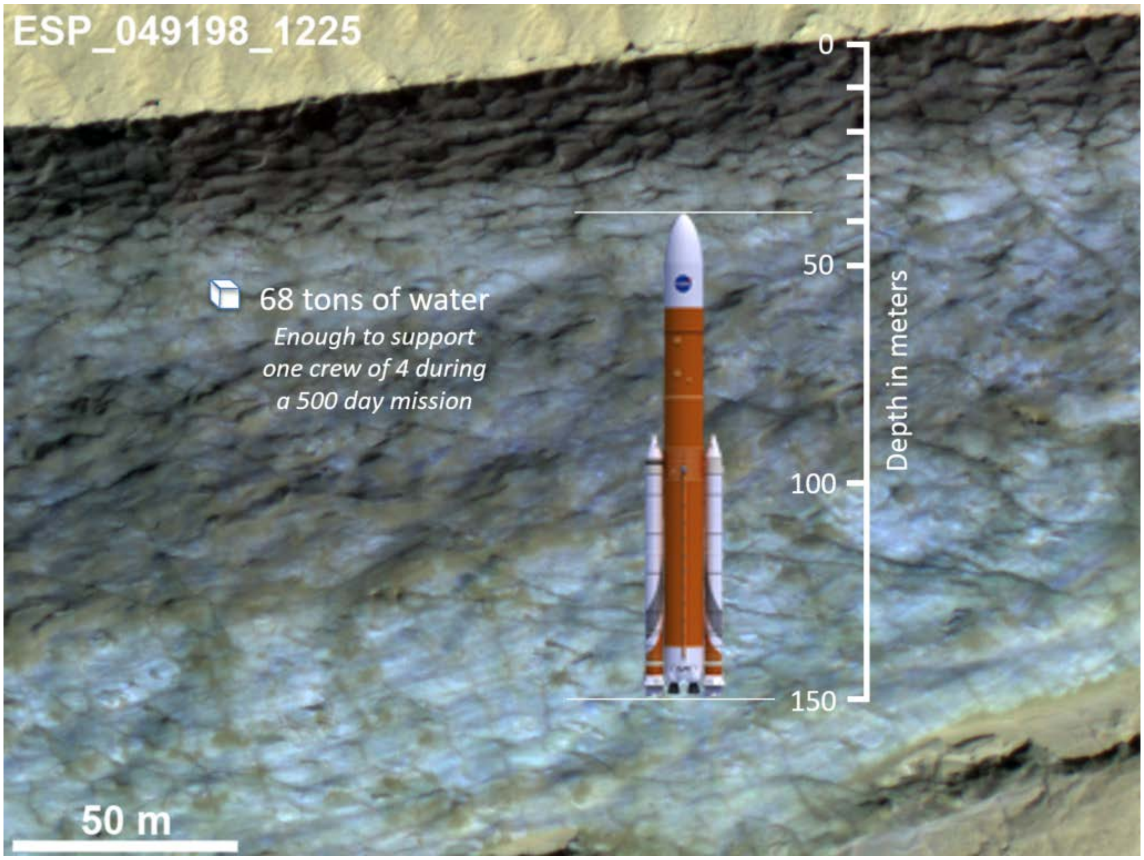

Fig. 4 Visual comparison for scale of exposed ice scarps on Mars with systems likely to be used for these Mars missions [12]

The Dundas et al group has been able to locate eight examples of exposed ice scarps, each measuring tens of meters in height. The location of these scarps, shown in Figure 5, are located well north and south of the equator, but still within the range of sites considered reasonable for future human missions [13]. Even though the number of examples are relatively few and their locations are at relatively high latitudes, their significance for future human missions rests in the fact that we now have a clearer picture of what lies buried at the dozens of other similar terrain features located in a wide swath in both the northern and southern hemispheres (Figure 5).

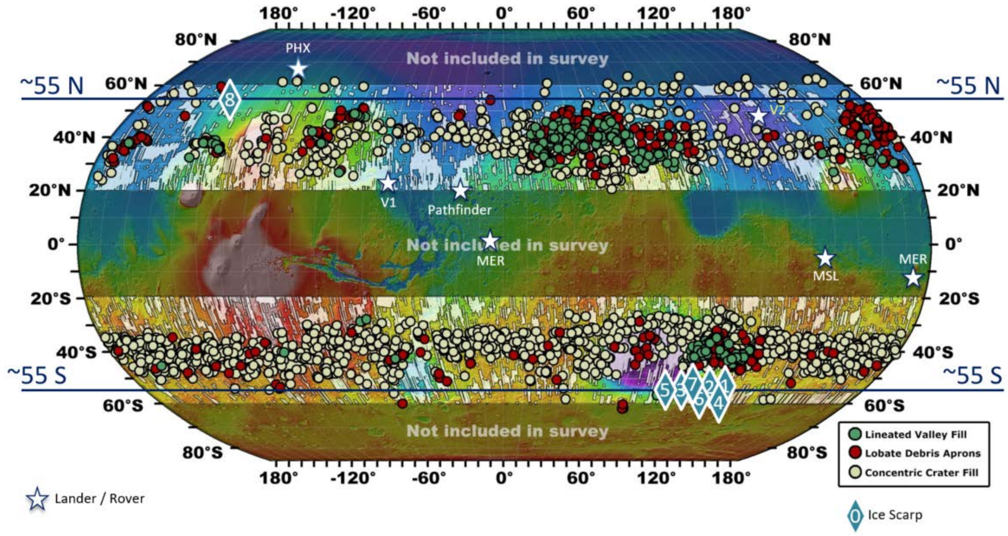

Fig. 5 Location of ice scarps identified by Dundas et al [12]

Unfortunately, the radars mentioned above were designed to look deep under the surface, and consequently cannot resolve near-surface features with much resolution. Dundas et al [12] were able to use visual data they gathered along with other sources to postulate a vertical profile of these ice sheets. This profile, shown in Figure 6, indicates that the overlying debris layer is likely to be just a few meters thick at the latitudes where they have located these scarps. The same theory that predicted the icy soils at high latitudes suggests that this debris layer will likely get thicker for terrain features that are closer to the equator [8]. But these estimated depths are not so great that drilling through the debris layer would be considered unreasonable for the latitude band shown in Figure 5.

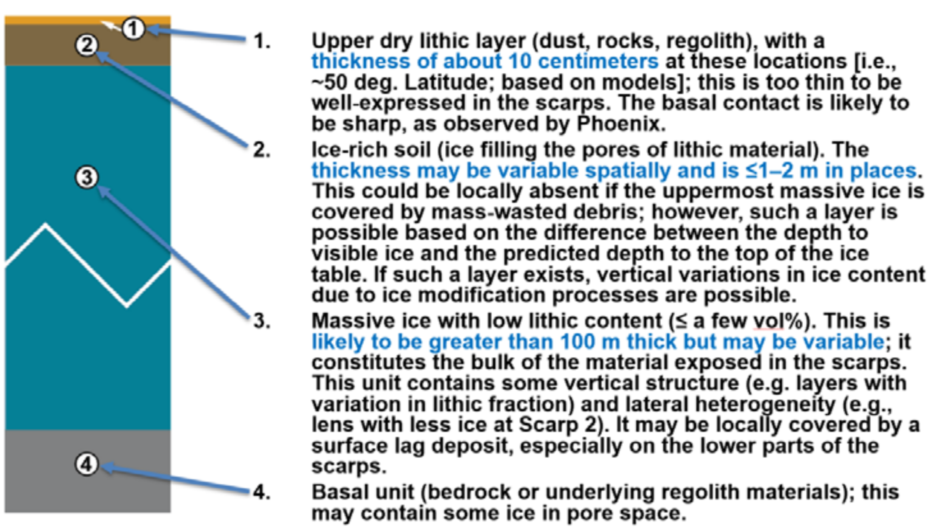

Fig. 6 Location of ice scarps identified by Dundas et al [12]

III. Rodriguez Well Description and Associated Systems

A review of available techniques for accessing and withdrawing water from these buried ice deposits led to a technique that appears to be feasible in the Martian environment: drilling through the overlying debris layer and creating an underground reservoir by heating the ice layer in place [3]. Subsurface water reservoirs were first designed and built by the U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) in the early 1960s for several U.S. Army camps located in Greenland [14, 15]. These reservoirs are commonly referred to as Rodriguez wells, or Rodwells.

From the Schmitt and Rodriguez report [14]:

> A Rodwell is developed by drilling a hole into snow or ice and then melting the ice in place using a heat source, typically recirculated hot water. The melt water then ponds when an impermeable strata in the snow or ice is reached or until refreezing melt water forms its own impermeable barrier. (This is necessary because melt water will not pond in the firn layer.) The melt water forms a cavity above the impermeable layer and remains as a liquid pool so long as sufficient heat is added to overcome the heat lost to both the surrounding snow or ice and the atmosphere above the pool of water. After a sufficient reserve capacity of liquid water has been established in the well, pumping can begin to supply potable water to the surface. The size and shape of the ponding cavity depends on the relative rates of melting and water removal by pumping and upon the rate of heat application to the pool:
>
> - With a large heat supply and small pumping rate the cavity can grow laterally rapidly.
> - If the pool is over-pumped, the cavity tends to develop rapidly downward (rather than laterally) due to the high temperature of the reservoir water.
> - The well will "collapse" (i.e., stop producing liquid water) if the rate of water extraction exceeds the rate of heat input necessary to maintain the liquid pool.

South Pole Station is currently using its *third* Rodwell to provide potable water, the first two having reached a depth at which it was no longer efficient to pump water to the surface.

Development of a Rodwell for the presumed Martian conditions described in the previous section will require drilling through the overburden layer and far enough into the ice layer so that the resulting cavity will not collapse due to the weight of the overburden. A cased hole through at least the overburden and possibly the upper ice layer will be required to prevent the overburden from collapsing into the hole, and will allow the option to seal and pressurize the cavity to some TBD level to minimize water sublimation. As a result, the following functional capabilities will be needed for an operational system on Mars:

- A drill that can penetrate the overburden layer and emplace a casing;
- A drill that can penetrate the ice layer (may or may not be the same as the overburden drill);
- A concept to melt and recirculate water within the Rodwell "melt pool."

Figure 7 illustrates a notional sequence of steps that these functional capabilities would be used to establish a functional Rodwell.

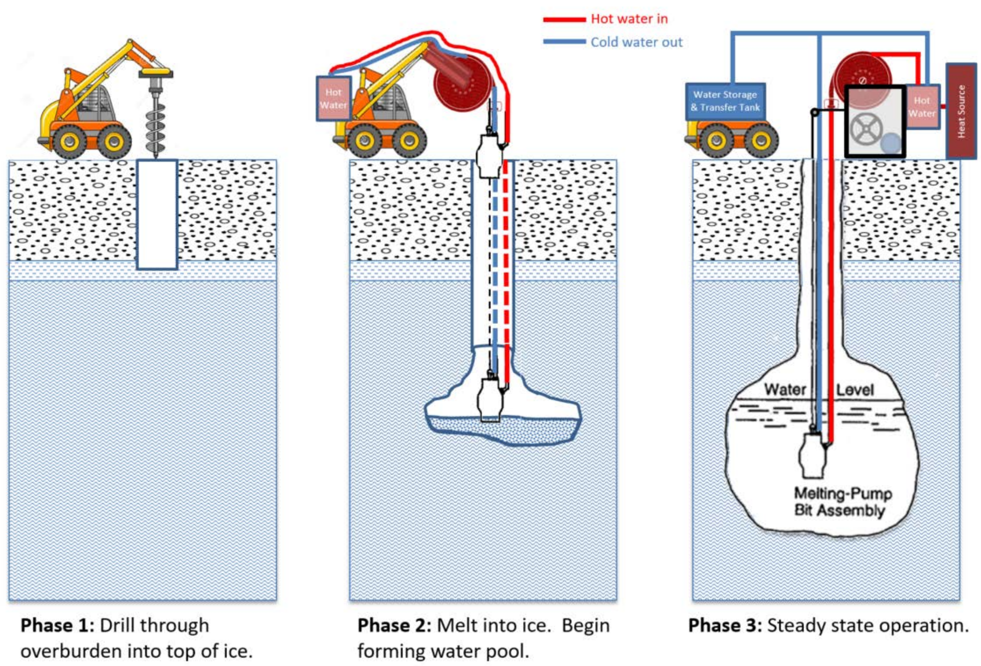

Fig. 7 Steps used to establish a Rodwell on Mars

An initial assessment of these functional capabilities has been carried out to estimate a notional configuration and its associated mass. Because this system is assumed to be used as part of a human surface mission, an initial assumption is that systems being used for other purposes by the human crew would also be available for supporting development of the Rodwell. Taking advantage of this assumption, this assessment included the use of two systems: (1) a fission power system to provide both electrical and thermal power, and (2) the chassis of a small pressurized rover for mobility across the surface. Figure 8 shows a concept for this small pressurized rover (on the left) and the chassis alone (on the right) that is sized to carry a payload of approximately 5 metric tons.

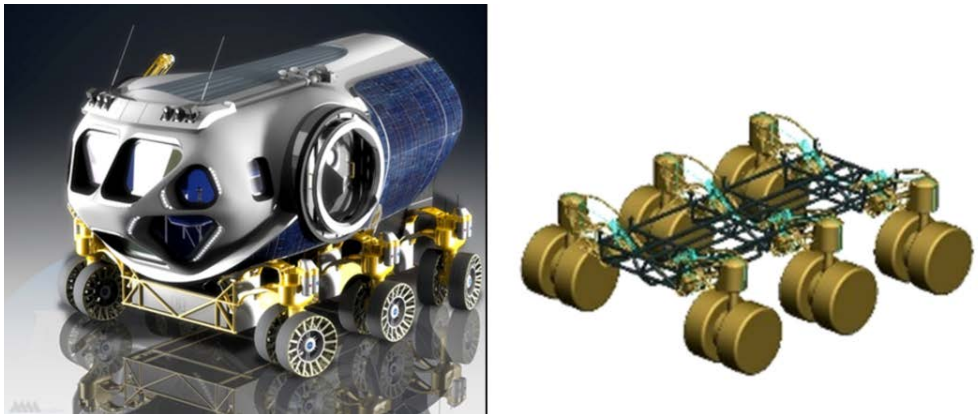

Fig. 8 A small pressurized rover used by the crew for Mars surface traverses (left) and the chassis for this rover (right) [NASA Images]

Figure 9 shows a simple layout of this chassis carrying the key systems needed to drill through the overburden and into the ice followed by pumping water into a separate (i.e., not shown) holding tank.

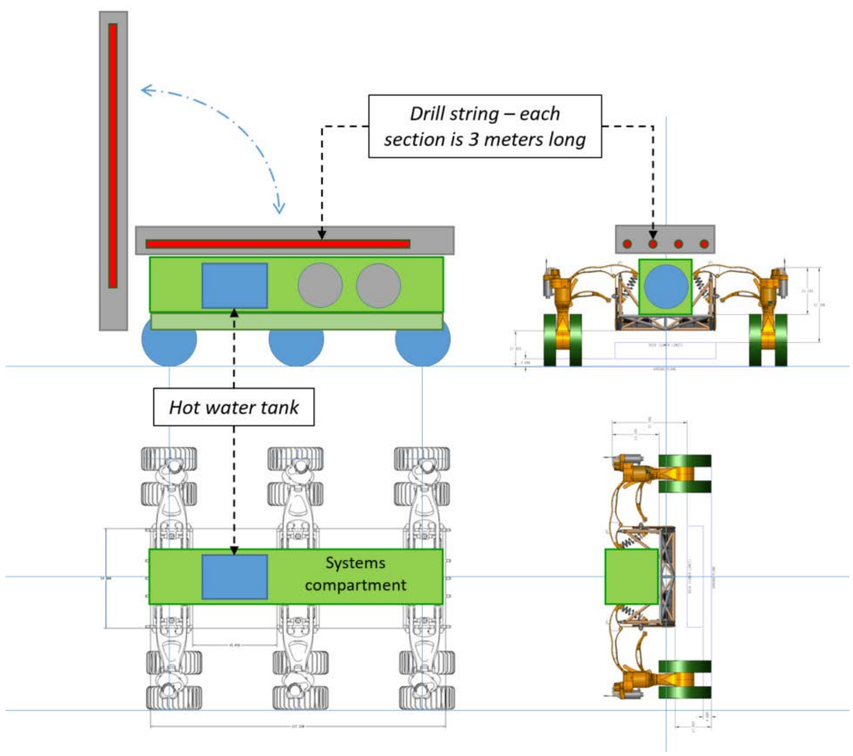

Fig. 9 The chassis for a small pressurized rover chassis configured to carry a Rodwell drilling and pumping system [Chassis images from NASA]

A mass estimate for this configuration is in Table 1. A recent study compares this system and its performance with several other ISRU systems designed to collect water on Mars [5]. The performance of this system is found to be very similar to other approaches using different technologies.

Table 1 System Mass Estimate for Initial Assessment Configuration

Functional Area	Subsystem	Subsystem Mass (kg)	System Mass (kg)
		Total	**4,771.2**
Transport			3,207.0
	Rover Chassis	3,207.0	
Surface Equipment			1,413.7
	Drill Support Structure	321.8	
	Drilling Water Supply Tank	158.5	
	Heat Exchanger Assembly	28.5	
	Drill Supply Pump	8.8	
	Hot Water Drill Spool and Reeler	110.1	
	Hot Water Drill Hoses, Cables, and Connectors	164.0	
	Pressurized Gas for Line Purge	22.7	
	Regolith Drill Carousel	100.0	
	Regolith Drill Spool, Reeler, and Cable	73.9	
	System Control Avionics	400.0	
	Water Filtration System	16.4	
	UV Sterilization System	9.0	
Subsurface Equipment			150.5
	Regolith Drill and Casing	115.0	
	Thermal Drill and Submersible Pump	35.5	

IV. Rodriguez Well Description and Associated Systems

Personnel at CRREL developed a computer simulation of the Rodriguez Well to support engineering analyses associated with this type of water well at a number of different polar locations [16], including South Pole Station in Antarctica and Summit Station in Greenland [17]. This computer simulation was built around an energy balance, tracking heat injected into the well, heat transferred to the air above the water pool, heat transferred from the air to the ice of the well cavity, and heat transferred from the water pool to the ice, causing some of the ice to melt into water that is eventually pumped out for use. The simulation does not model any of the other physical aspects of the well, such as the circulation of water within the water pool or air circulation above the water pool. It also does not model the development of an ice layer on the water pool, as is sometimes seen in these Rodriguez Wells in terrestrial locations.

But this simulation has been sufficient for trade studies of water production approaches at different station located in the Arctic and Antarctic [17]. It was also used for a preliminary assessment of using this approach for future human missions to Mars [3]. This assessment indicated that the Rodriguez Well approach could be a useful technique for these Mars missions under certain circumstances, and could also offer an opportunity for a significant change in the approach to these missions.

In this preliminary assessment of Rodriguez Well use on Mars, it was recognized that there are significant differences in the environments of Earth and Mars that were not accounted for in the simulation. Because the CRREL computer model is designed primarily to model the energy balance between air, water, and ice within the well cavity, it is the terms associated with this energy balance that must be examined and changed within the model. Water and ice are expected to have the same physical characteristics on Mars as they have on Earth, so no changes are required in the simulation with respect to these two constituents. However, the air on Mars is primarily carbon dioxide and will likely be at a pressure in the range of 6 to 10 millibars. Because air temperature and density are important factors in the energy balance, the constant pressure specific heat and gas constant (for the ideal gas law – assumed in the simulation but likely requiring a change to reflect the low pressures on Mars) must be changed to reflect this carbon dioxide atmosphere. The heat transfer coefficients between water and air and between air and ice are also likely to be different on Mars. Experiments that have yet to be conducted (discussed in Section V of this paper) will investigate appropriate values for these two parameters. However, other investigators have looked into this heat transfer difference for other reasons (e.g., Hecht [18] or Sears and Moore [19]). These sources were used to provide preliminary heat transfer rates that could be incorporated into the simulation to gain some understanding of the effect likely to be seen in a Rodriguez Well operating on Mars.

Representative of the sources reviewed for heat transfer rates at Martian surface conditions was a report by M. Hecht [18] documenting the results of an experiment he conducted to determine water evaporation rates likely to be experienced by water or ice exposed on the surface of Mars. Figure 10 shows the results obtained by Hecht at two pressure extremes – terrestrial pressure conditions on the right side of the graph and Martian pressure conditions on the left. Notice that the total heat loss is almost the same on both planets when conditions other than pressure are similar. From this graphic and with the delta-T of 73 K (from Hecht [18]), we derived a total heat transfer rate for representative Martian conditions of 4.11 W/m^2-K (0.725 Btu/h-ft^2-R).

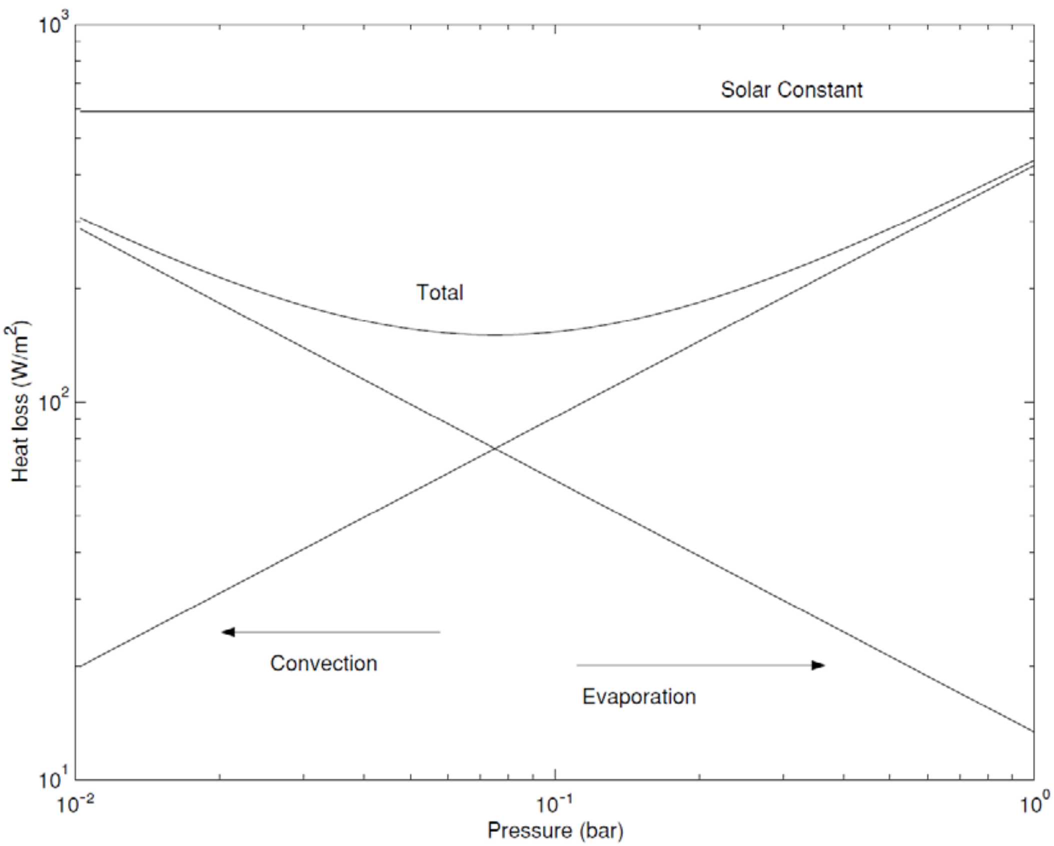

Fig. 10 This is a copy of Figure 8 from Hecht [18] showing the "convective heat transfer between a 273 K surface (water) and a 200 K atmosphere compared to evaporative cooling. The right-hand boundary reflects terrestrial conditions; the left reflects [M]artian conditions."

Table 2 summarizes the terrestrial and Martian environmental parameters used in the CRREL simulation for the previously mentioned preliminary assessment [3] and the values used for a preliminary assessment of the performance of a Rodriguez Well under representative Martian surface conditions. The terrestrial heat transfer values are those reported in the CRREL report by Lunardini and Rand [16]. The Martian heat transfer values were taken from values documented in the paper by Hecht [18] as discussed above.

Table 2 Environmental Parameters Used in the CRREL Simulation of a Rodriguez Well

Parameter	Earth		Mars	
	(SI/metric)	(SAE)	(SI/metric)	(SAE)
Atmospheric Pressure	1013 mb	14.7 psi	8.0 mb	0.116 psi
Gas Constant	287 J/(kg-K)	53.4 ft-lbf/(lbm-R)	189 J/(kg/K)	35.1 ft-lbf/(lbm-R)
Atmospheric Specific Heat	1.01 kJ/(kg-K)	0.240 Btu/(lb-R)	0.834 kJ/(kg-K)	0.199 Btu/(lb-R)
Heat Transfer – Water to Air	5.67 W/(m^2-K)	1.00 Btu/(h-ft^2-R)	4.11 W/(m^2-K)	0.725 Btu/(h-ft^2-R)
Heat Transfer – Ice to Air	5.67 W/(m^2-K)	1.00 Btu/(h-ft^2-R)	4.11 W/(m^2-K)	0.725 Btu/(h-ft^2-R)

There are other environmental factors known to differ between Earth and Mars that should be accounted for in simulations of this type. Two of the more apparent factors are (1) gravity, and (2) atmospheric pressure close to the triple point of water. Gravity will affect the buoyancy of atmospheric constituents and thus could affect the manner in which air and water vapor circulate above the water pool in the Rodriguez Well cavity, affecting the way heat is transferred by the air. The current version of the CRREL simulation assumes that the air is well mixed and does not specifically try to simulate air circulation. This is an area for future investigation. Atmospheric pressure near the triple point of water will also affect the phase of water in the cavity. At present, this is also an area of acknowledged future investigation, but for purposes of this simulation it is assumed that the water pool temperature will be maintained close to the freezing point of water, and the pressure in the cavity will remain high enough to allow the water pool to exist in liquid form (recall also that the typical means of supplying heat to the water pool is by recirculating water at a high rate).

In previously reported work [3], an example case using terrestrial environmental parameters, but with an ice temperature representative of what is expected on Mars (-80 °C), was found to be capable of withdrawing water at a rate of 379 kg/day (100 gallons/day) indefinitely using 10 kW (32,000 BTU/hr) of power. Changing all of the parameters from their terrestrial values to the Martian values listed in Table 2 was found to actually improve the performance of the Rodriguez Well. Figure 11 shows the results of this comparison.

From the previous work [3], 10 kW of heat input into the well was found to produce a pool of water that remained at a constant volume when water was withdrawn at 379 kg/day (100 gallons/day) rate. If the amount of heat put into the well was increased to 20 kW, the pool was found to grow very large, indicating that the additional heat was just making more water that was not being used. Decreasing the amount of heat put into the well below 10 kW caused the well to be pumped dry, as the smaller amount of heat was not sufficient to melt ice at a rate equal to the withdrawal rate.

When the simulation was run with Martian environmental parameters and similar amounts of heat put into the well (all other parameters the same), it was found that ice was being melted at a faster rate than that seen in the terrestrial simulation. Under these Martian conditions, both the 10 kW and 20 kW cases resulted in ice being melted faster than it was being withdrawn; it was only when the amount of heat was reduced to 9 kW that the rate at which ice was being melted matched the withdrawal rate.

At present, these results are based on an assumption that the heat transfer rates described by Hecht and others apply in a virtually closed chamber compared to an "open" environment on the surface of Mars with (potentially significantly) different boundary conditions. The next section describes a series of experiments in the development stages at the NASA Johnson Space Center to more closely model the Rodriguez Well situation and gather data regarding the heat transfer rates for this closed environment.

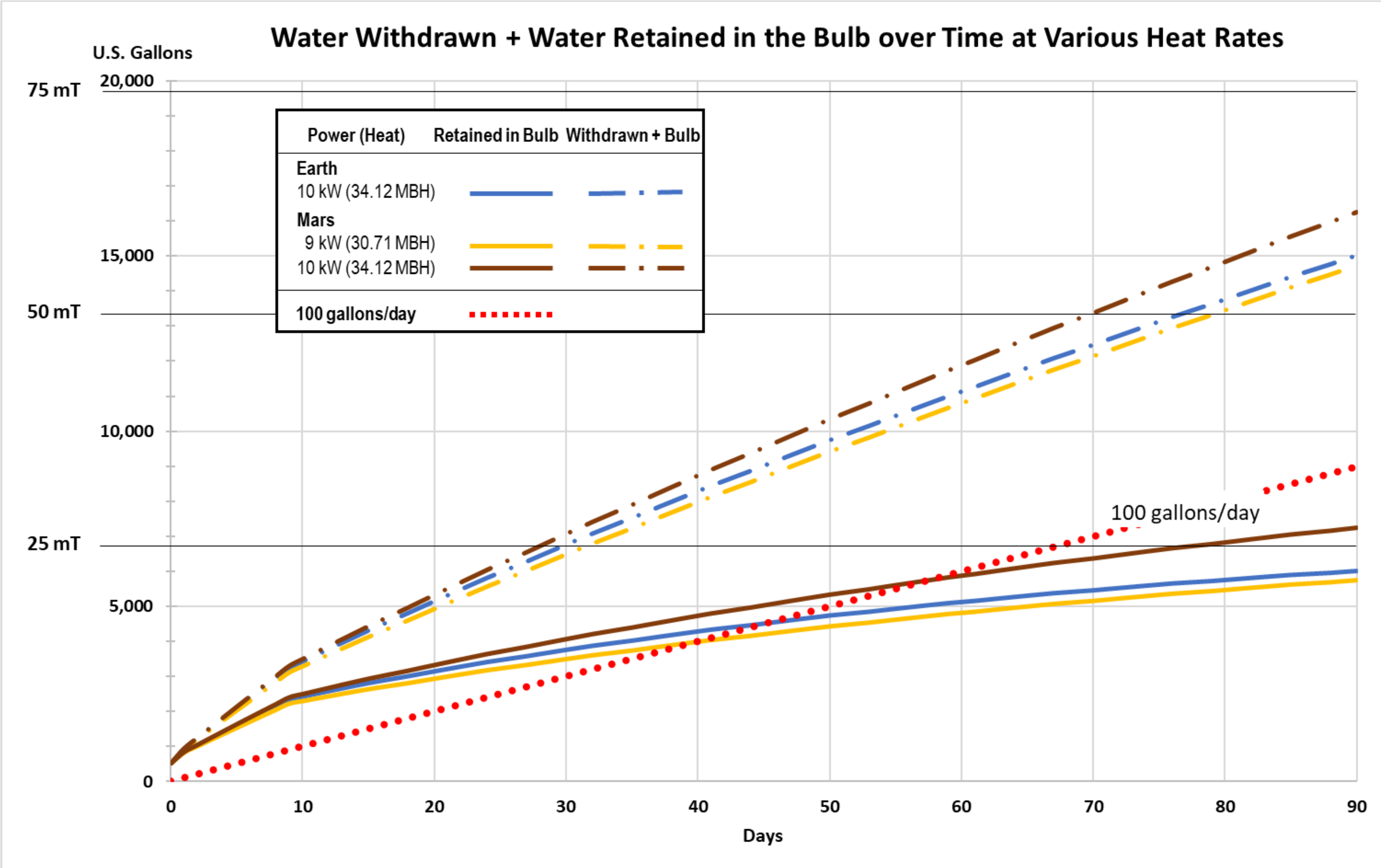

Fig. 11 Performance of a simulated Rodriguez Well using terrestrial and Martian environmental parameters.

V. Additional Experiments to determine Martian Environmental Parameters

The previous section described results of a heat transfer experiment carried out by Hecht [18] that is similar to the conditions likely to be found in a Rodriguez Well. Consequently, the heat transfer parameters resulting from that experiment were used in the CRREL simulation to gain an indication of the effect these Martian parameters will have on the Rodriguez Well performance compared with previous results using terrestrial parameters.

However, there are still several aspects of the Rodriguez Well that are different from those modeled by Hecht and are thought to have a possible impact on the results as they apply to a well of this type.

First among these Rodriguez Well peculiar aspects will be the continuous introduction of heat – typically by recirculation of heated water from the surface – that is intended to keep the underground pool of water in a liquid state. Related to this is the option to keep this water at a desired temperature by means of changing the amount of heat introduced from an external source. The second peculiar aspect is the fact that the air above the water pool is likely to be saturated with water and that this water will freeze on the sides of the cavity above the water pool.

To investigate the general behavior of a Rodriguez Well under Martian environmental conditions, and to gain a better understanding of the effects of these peculiar aspects of the Well, two experiments are being designed at the NASA Johnson Space Center. The first experiment is intended to determine the heat transfer from water to air; the second is intended to determine the heat transfer to/from air and ice. Both experiments will use a relatively small bell jar test chamber similar to the one shown in Figure 12. The test volume in this chamber is approximately two feet in diameter and approximately two feet tall. This volume is cooled by a liquid nitrogen shroud.

For both experiments the test chamber will be filled with carbon dioxide at a pressure and temperature representative of Martian surface conditions expected to be encountered (approximately 8 mb and -60 °C). For the first experiment, an insulated container will hold a small pool of water. A heater element will be placed in the water and will be used to keep the pool of water at a constant temperature (likely just a few degrees above freezing). The amount of power needed for the heater element to hold the water at the desired temperature will be correlated to the heat transfer from water to air. Similarly, the heat transfer from ice to air will be determined by measuring the amount of power needed by a heater element to hold a small block of ice (also in an insulated container) at a constant temperature (likely not too far below freezing) while the air above it is at the Martian temperatures and pressures mentioned above.

Fig. 12 The small two-foot diameter bell jar that will be used for the heat transfer experiments will be similar to this unit

A mass balance is also being considered for these experiments to measure the mass of water lost to evaporation during these experiments. This evaporation rate will provide a means of comparison with other similar experiments, such as those of Hecht, to help understand any differences encountered.

VI. Summary

Several recent lines of research have shown that there are sources of potentially large quantities of water at many locations on the surface, including regions considered as candidates for future human missions. If these reservoirs of water can be accessed in support of human Mars missions, a dramatic change in the approach to these missions could result. This paper has focused on one possible source of abundant water and a means to access it. Together, these factors could allow this dramatic change to come about. Recently published descriptions of exposed ice sheets at latitudes that are within the range of potential human surface missions have added significantly to the evidence that a numerous and widely distributed class of terrain features are actually buried ice sheets. A concept called a Rodriguez Well was described and results from an earlier assessment of this concept for use on Mars were reviewed, including a preliminary concept and mass estimate for the surface equipment needed to develop and operate such a well on Mars. In addition, this paper described refinements to the earlier assessment, incorporating changes to a computer simulation that more accurately represent environmental conditions on Mars. These modifications to the simulation were shown to make noticeable changes in the results compared to earlier results, but these changes were in a direction that actually improved the performance of the well when operating at Mars surface conditions. But these modifications were acknowledged to be based on experimental results that were similar but not the same as those expected in the Rodriguez Well. Consequently, two experiments were briefly described that are currently being developed to provide results based on conditions that more closely reflect those expected in the well. Future work will compare results from these two experiments with previous work and show the impact to simulated operation of a Martian Rodriguez Well.

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